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SCIENCE SERVICES DIVISION

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VELA T/7701

ANALYSIS OF K-LINE WAVENUMBER SPECTRA FROM THREE WMO NOISE SAMPLES

ADVANCED ARRAY RESEARCH

Special Report No. 2

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SECTION I
INTRODUCTION

In order to design an array of vertical and horizontal seismometers which could enhance teleseisms at WMO, it was desirable to have a detailed study of the noise pattern there. Therefore, this report discusses the analysis of the one-dimensional wavenumber spectra obtained from noise samples NS1, NS2, and NS3 recorded on 25 April 1962, 1 June 1962, and 27 April 1962, respectively. Previous reports presented the history and past processing of these noise samples[1,2,3].

The one-dimensional wavenumber spectra (K-line spectra) are physically interpreted as projections of two-dimensional wavenumber spectra onto one dimension. In the case of the WMO array, three K-line spectra were computed for each frequency investigated. The three lines were in directions parallel to the three sides of the triangular array (Figure 1). Although knowledge of the spectral projections on the three directions is basically inferior to knowledge of the two-dimensional spectrum itself, the exceptionally high resolution of these K-line spectra allows a much finer analysis of the WMO noise samples than was possible previously with the low-resolution two-dimensional spectra.

The basic input data for calculating these three one-dimensional wavenumber spectra are the crosspower matrix $\left[\Phi_{ij}(f)\right]$ where f is the frequency and where i and j range over the ten seismometers in the array.

The major achievement of the analysis is the identification of broadband 0.2 to 1.0 cps Rayleigh-wave energy coming from the lakes Lawtonka and Elmer Thomas in the northeast and of high-velocity P-wave energy. In addition to the northeastern Rayleigh energy and the high-velocity energy appearing at all frequencies from 0.2 cps to 1.0 cps, there is some indication of isotropic (nondirectional) Rayleigh-wave energy.

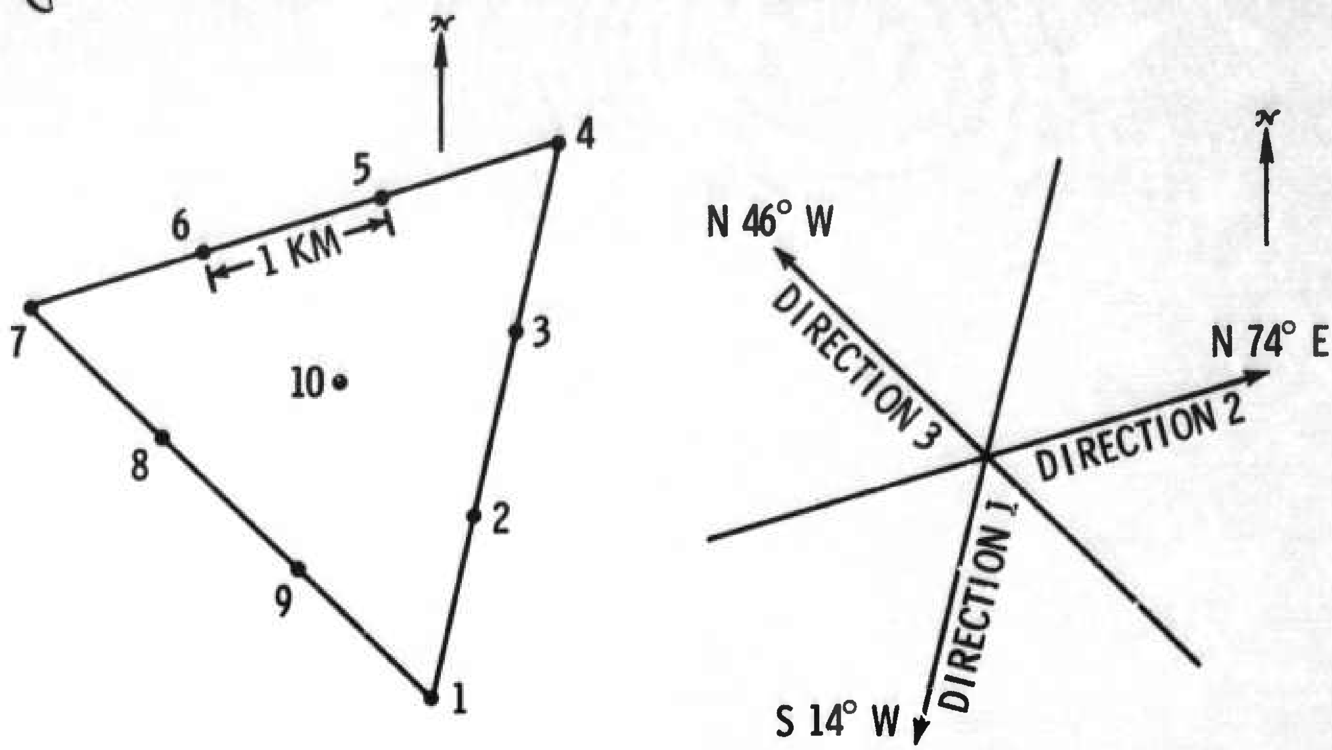


Figure 1. Array Layout and Direction of Arms Along Which K-Line Spectra Are Taken

Above 1.0 cps the peaks on the K-line spectra are disorganized and a meaningful analysis is difficult. This happens because at higher frequencies, wavelengths become comparable to the inhomogeneous geology at WMO and the interference of the wave becomes more pronounced. However, at 2.0 cps in the K-line spectra, a sharp peak consistent in all three noise samples is noticed. The aliasing properties of the WMO array unfortunately prevent picking a unique direction and velocity for this energy.

SECTION II

DESCRIPTION OF K-LINE SPECTRA

K-line spectra for Noise Sample 1 (Figure 2) are obtained for 20 frequencies from 0.2 to 3.0 cps, with an increment of 0.1 cps from 0.2 to 1.2 cps and an increment of 0.2 cps thereafter. Figures 3 and 4 show K-line spectra for Noise Samples 2 and 3, respectively.

Wavenumber power density spectra and integrated wavenumber power density functions are computed at each frequency for each of the three directions. The final interpretation is obtained by combining the information received from all of the graphs.

For each wavenumber spectrum (plotted in db vs wavenumber in cycles/km), the 0-db level indicates the spectrum's average value. In these wavenumber plots, the solid vertical line at k=0 represents infinite apparent velocity; i.e., the wave propagation is perpendicular to the direction along which the wavenumber spectrum is measured. Dashed lines on either side of this line show apparent velocities of 8 km/sec and 3 km/sec. Note that the 3 km/sec lines move off the figures after the 1.6 cps plot and appear as aliases at higher frequencies. Aliasing occurs at the wavenumber fold-over value, which is 0.5 cycles/km. The foldover wavenumber is equal to 1 divided by 2 times the average spacing between seismometers along each arm; average spacing in this case is 1 km. The right halves of the wavenumber spectra show the energy going in the directions of the arrows given in Figure 1. The normalized integrated wavenumber power density function is

$$\int_{-K}^{k} P(k)\, dk$$

with

$$\int_{-K}^{K} P(k)\, dk = 1$$

where P(k) is the wavenumber power density spectrum and K is the foldover wavenumber. This function has been plotted in fractional power vs wavenumber in cycles/km. These integrated spectral plots are particularly useful in that they facilitate measurement of the amount of power within any given wavenumber (or velocity) band.

To save space, a discrete function marked by small x's appears superimposed on these plots. These x's show the fractional power which is unpredictable when one tries to predict from a line of seismometers the output of the next seismometer in line. In particular, the far right x is the fractional mean square error in predicting one seismometer ahead (about 1 km) using three seismometers in a line. The next two x's give the fractional mean square error using two seismometers and one seismometer, respectively. The decrease in error as the number of seismometers increases is self-explanatory.

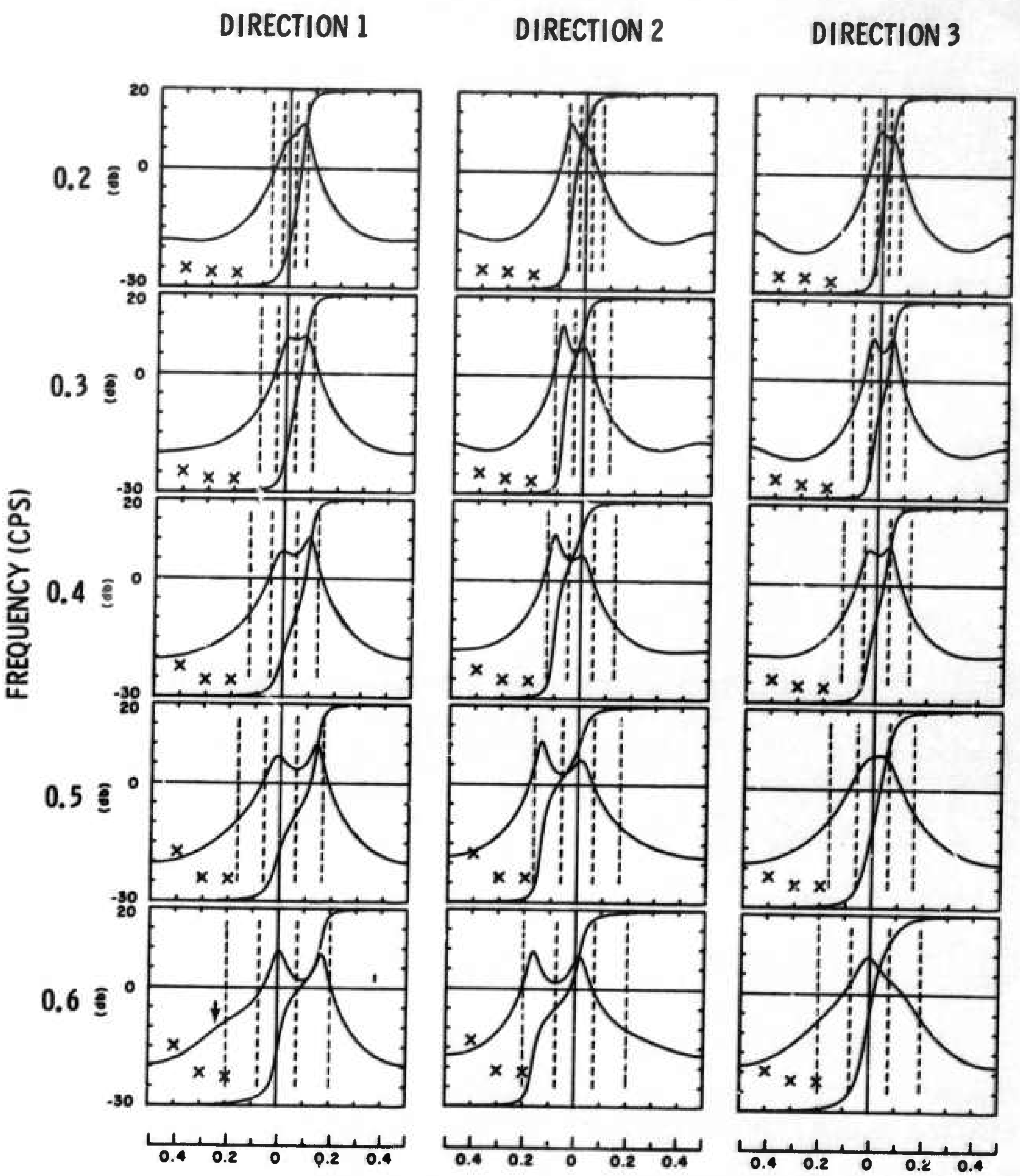
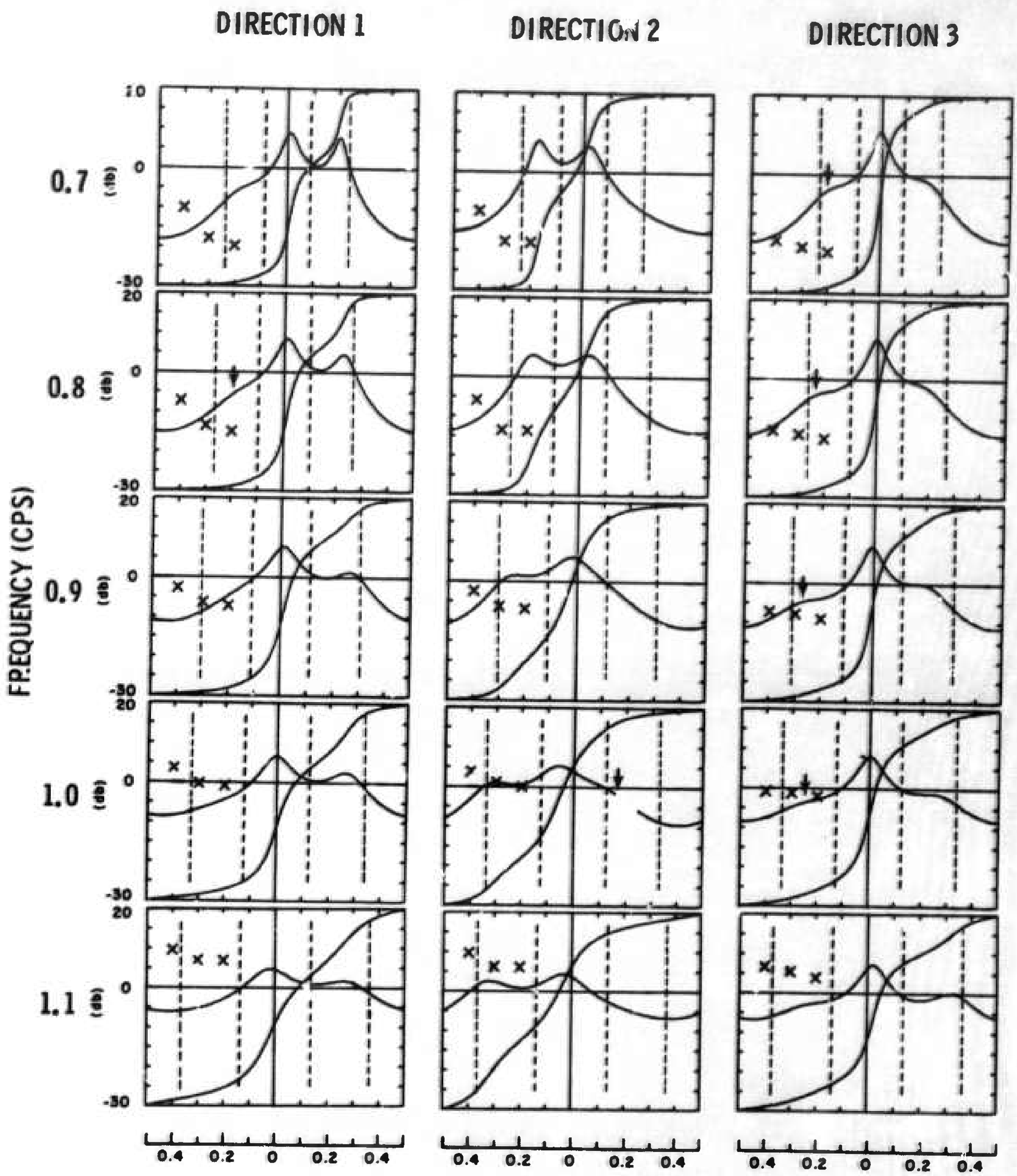


Figure 2. Wavenumber and Integrated Spectra from WMO Noise Sample 1



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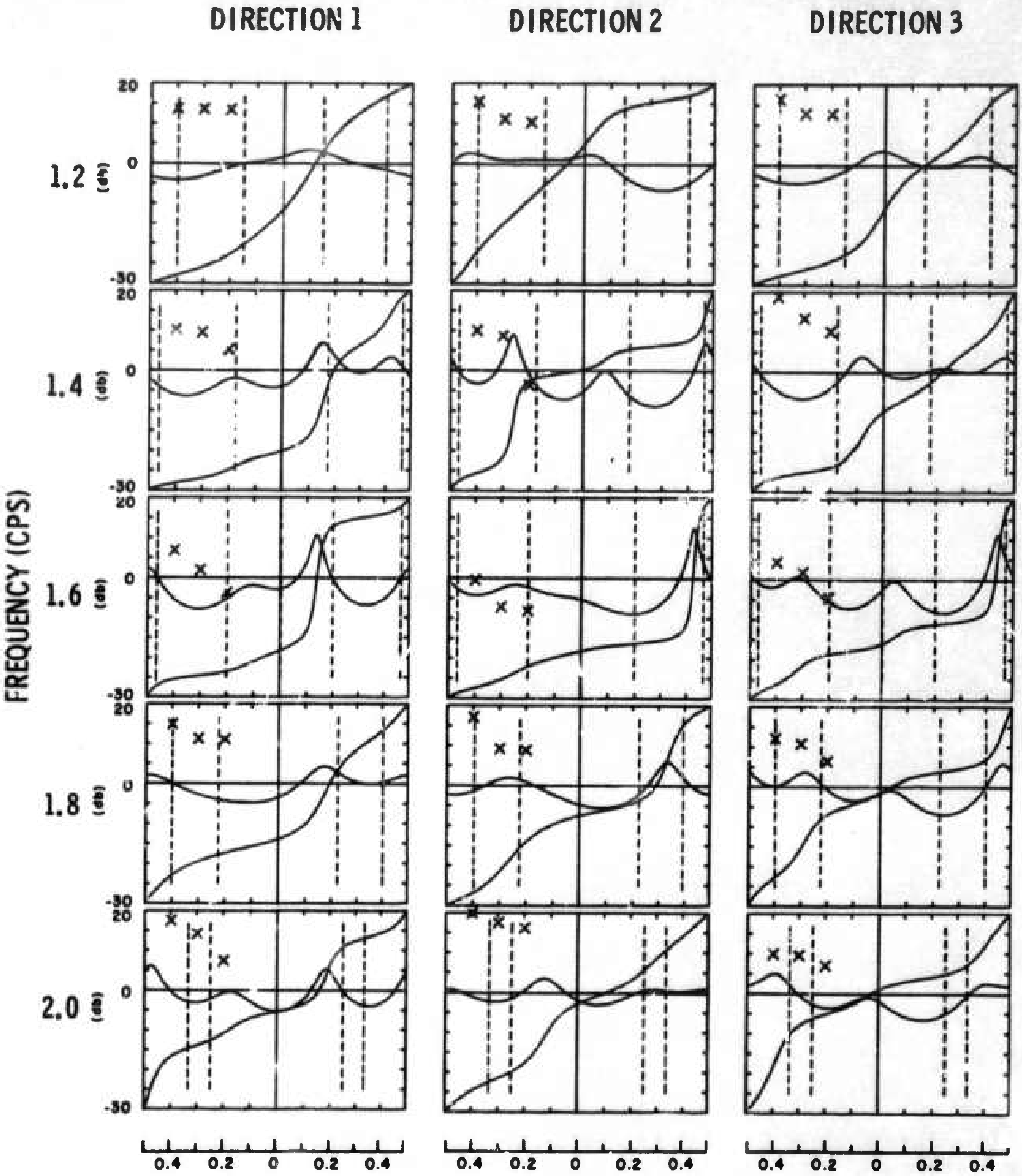

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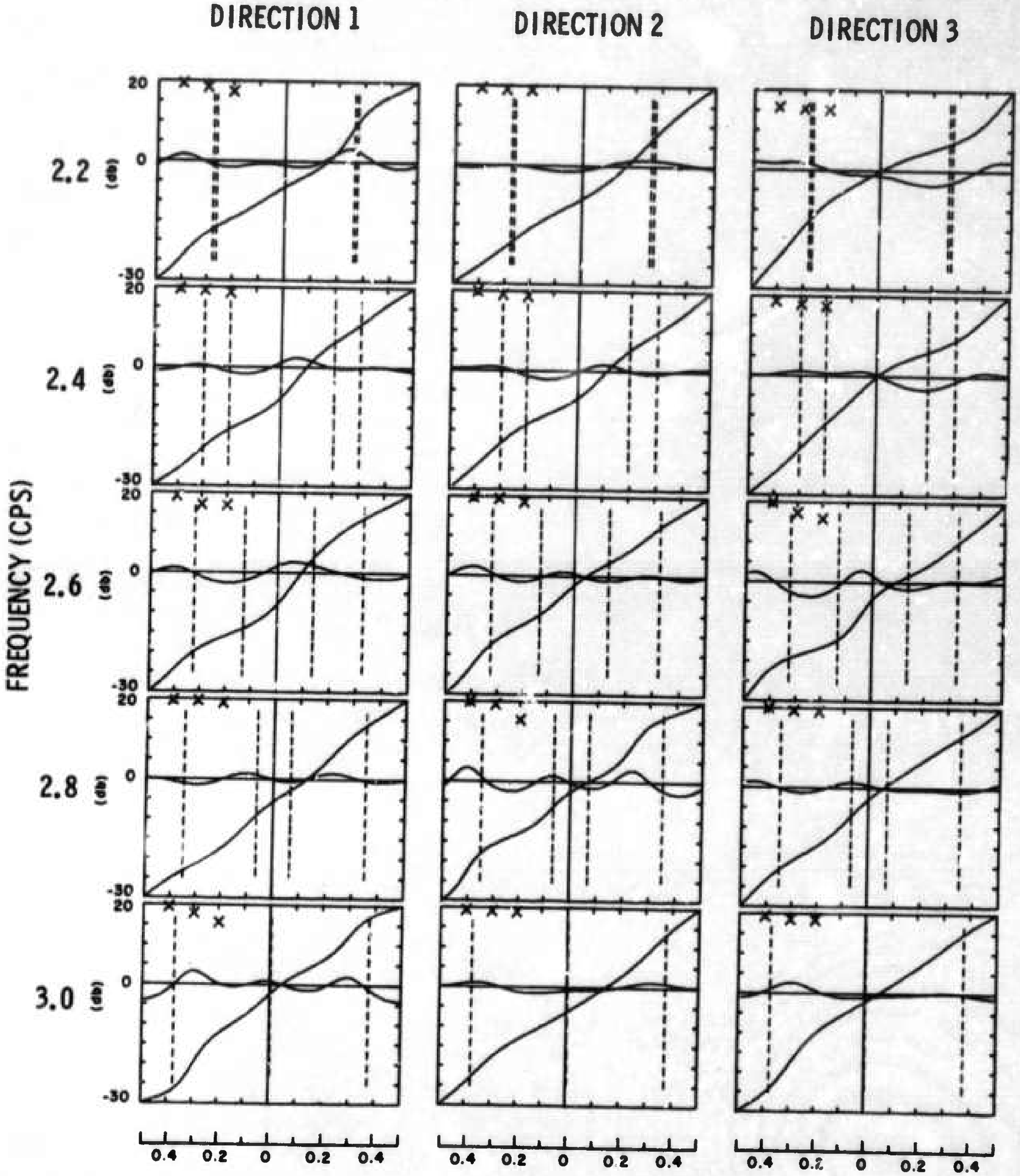

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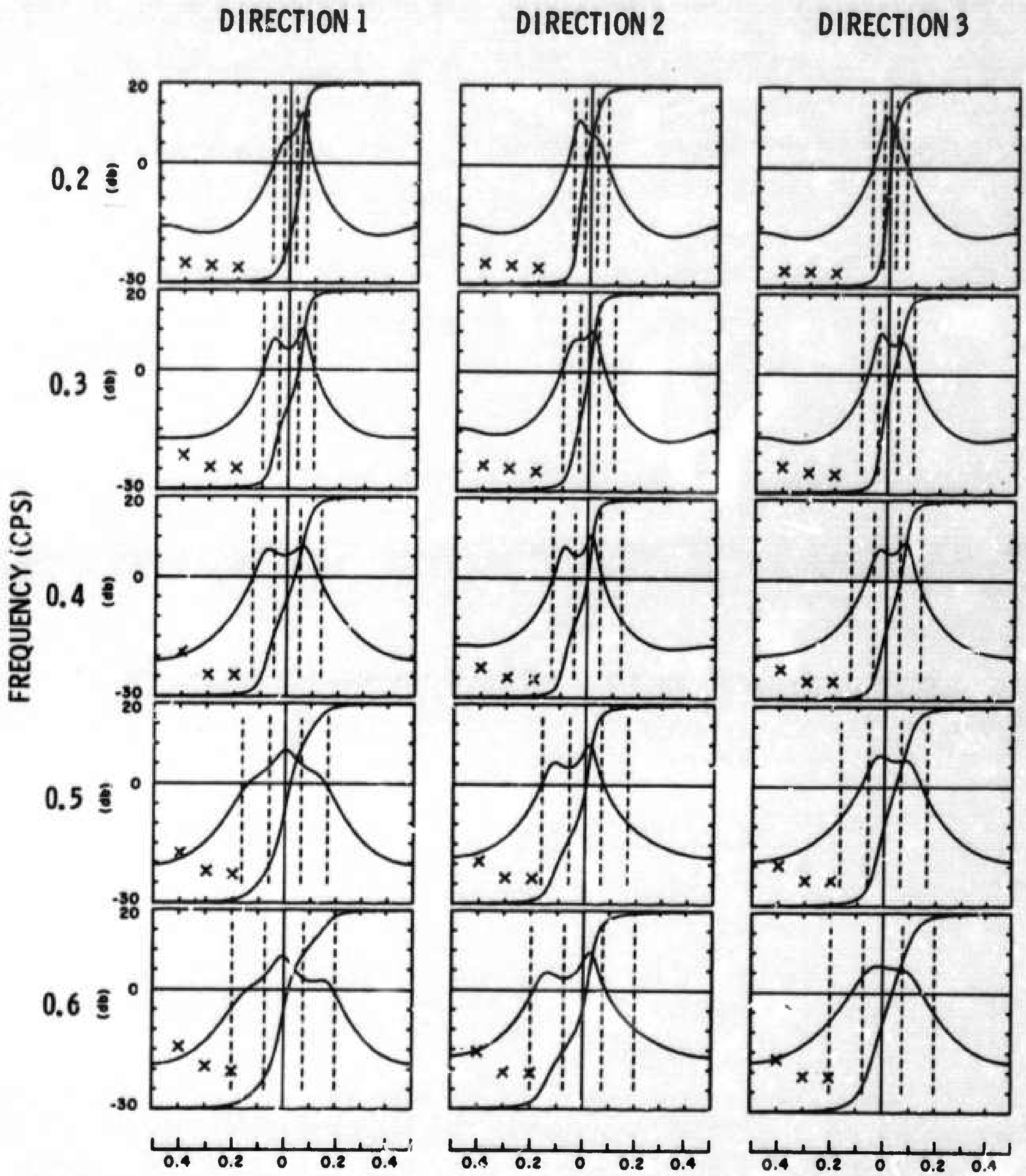
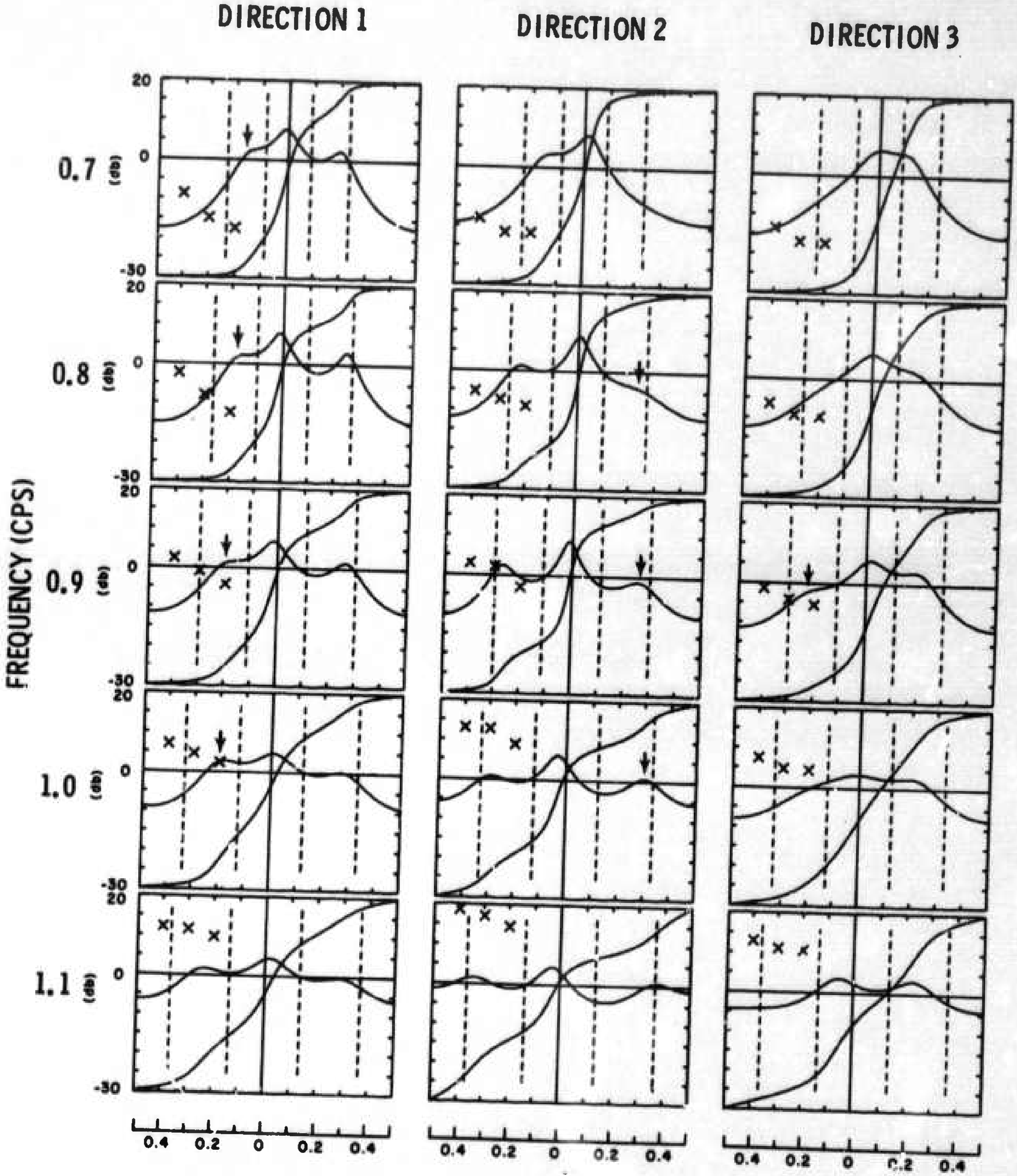


Figure 3. Wavenumber and Integrated Spectra from WMO Noise Sample 2



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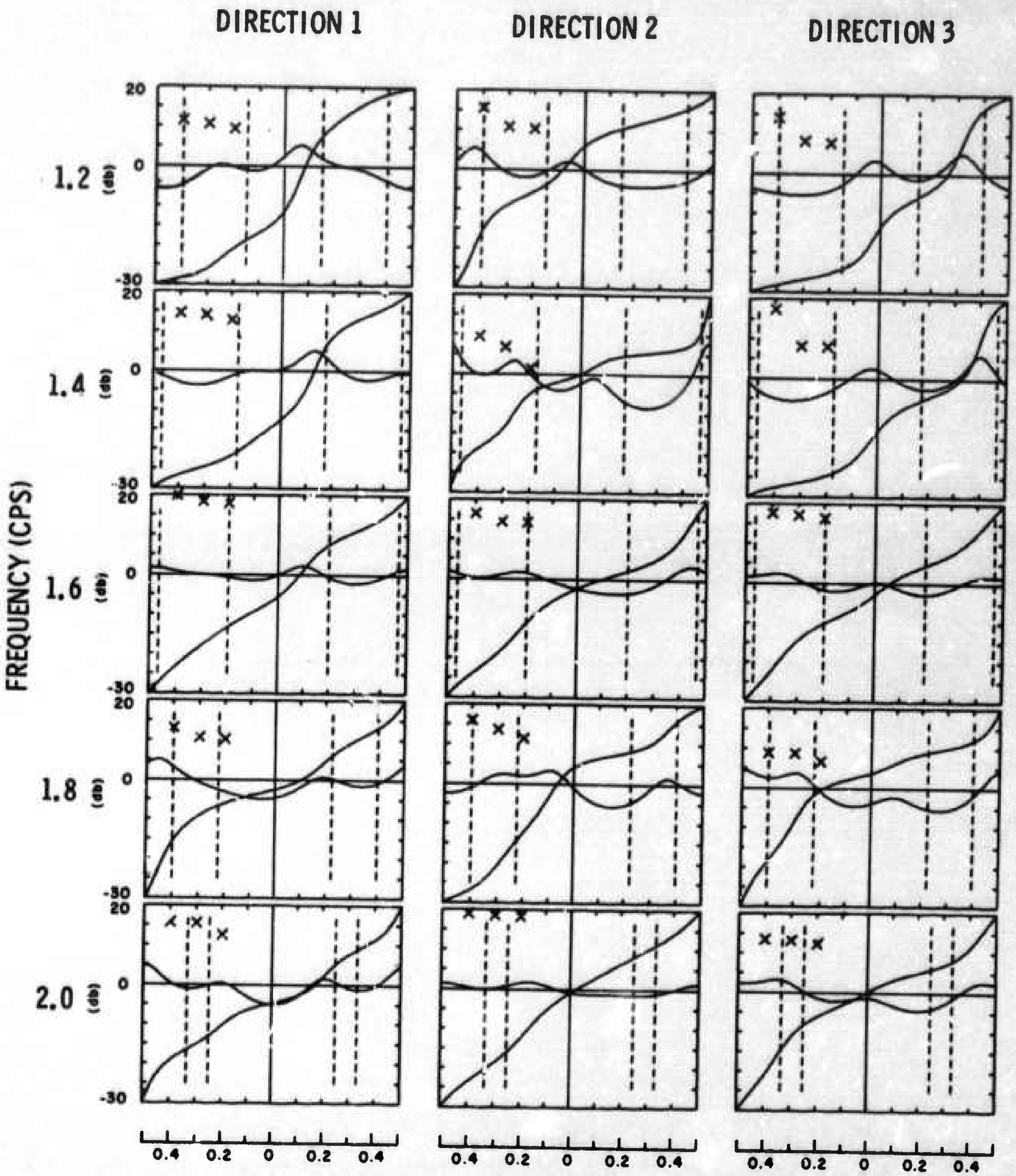

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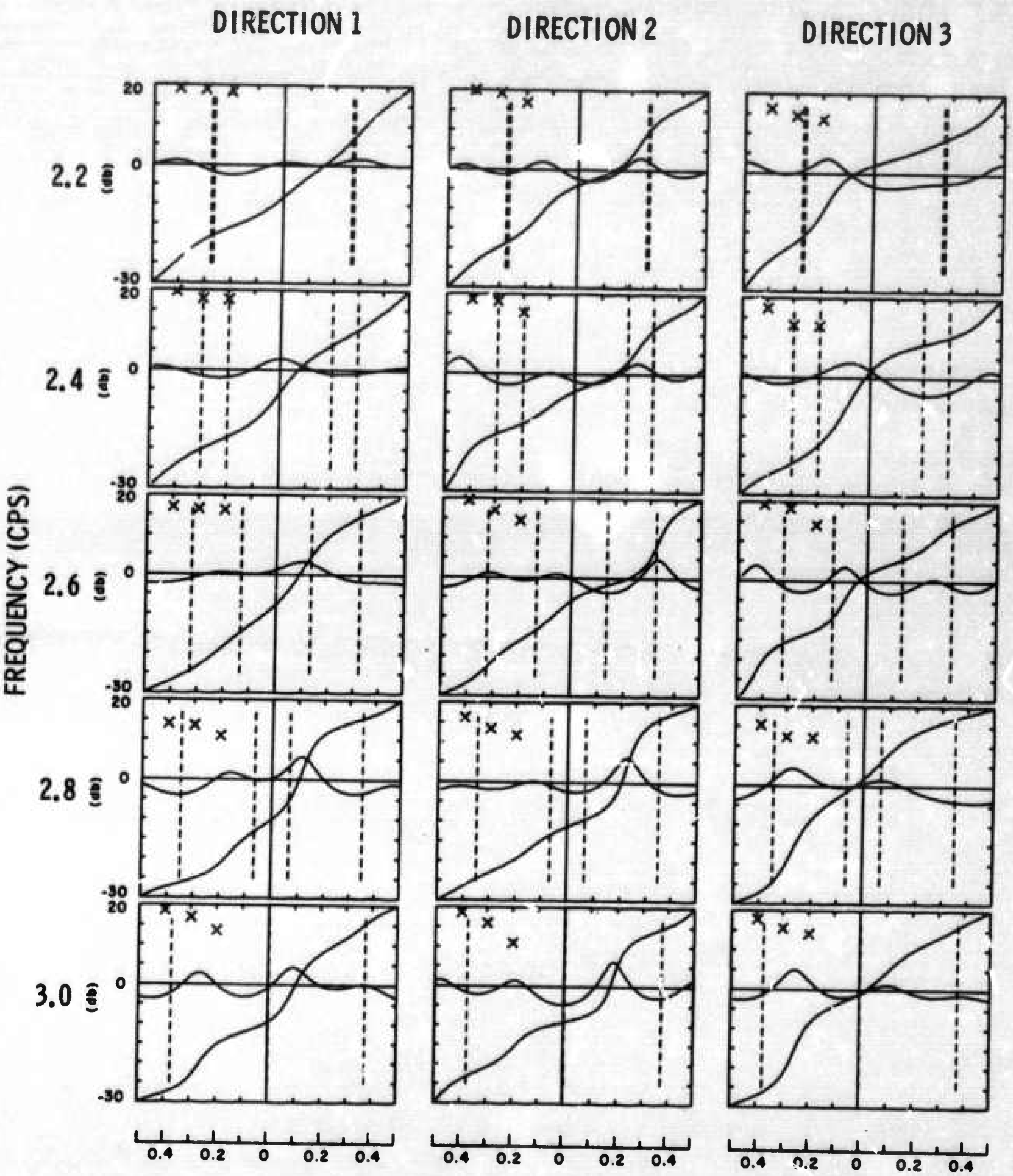

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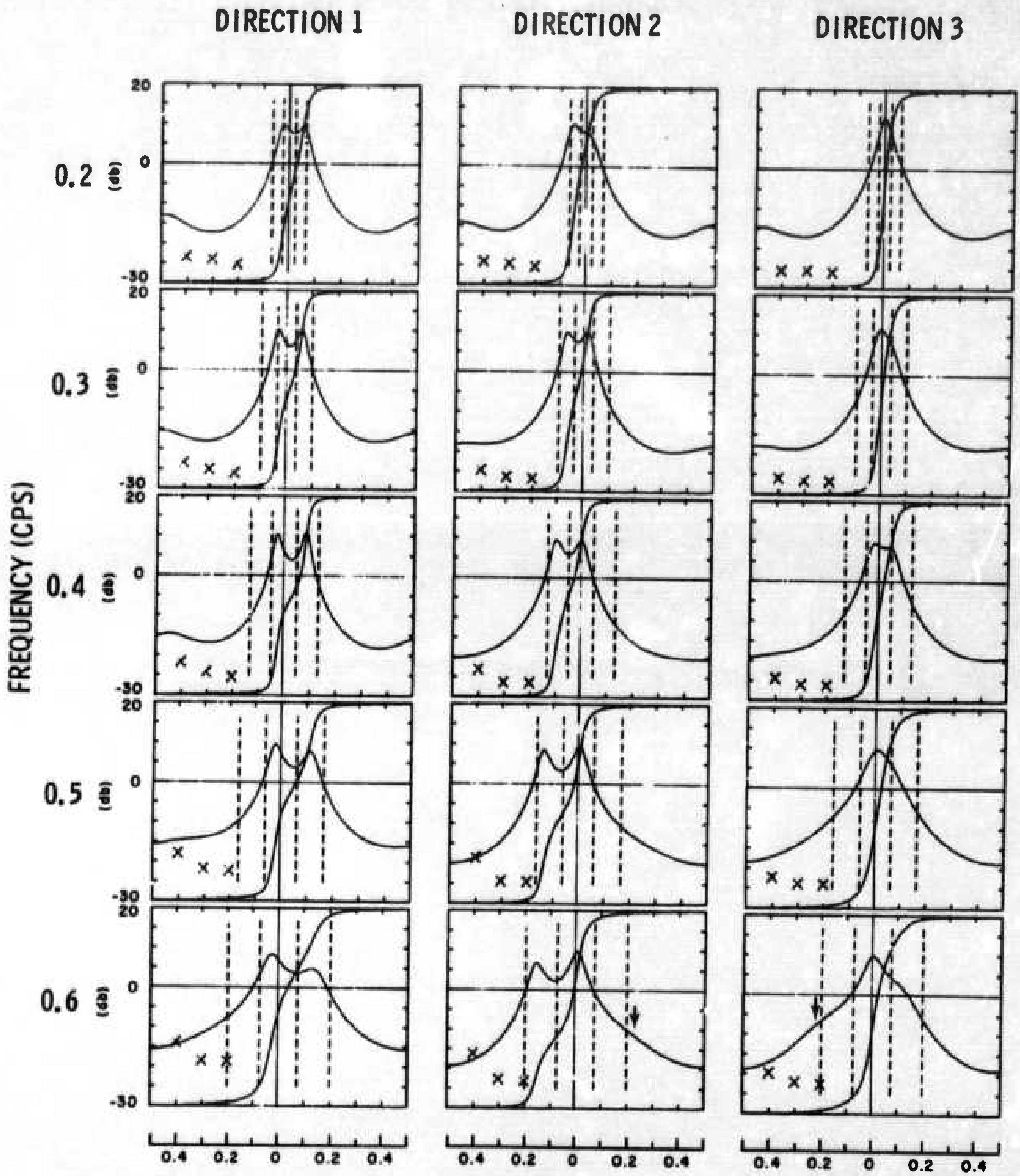
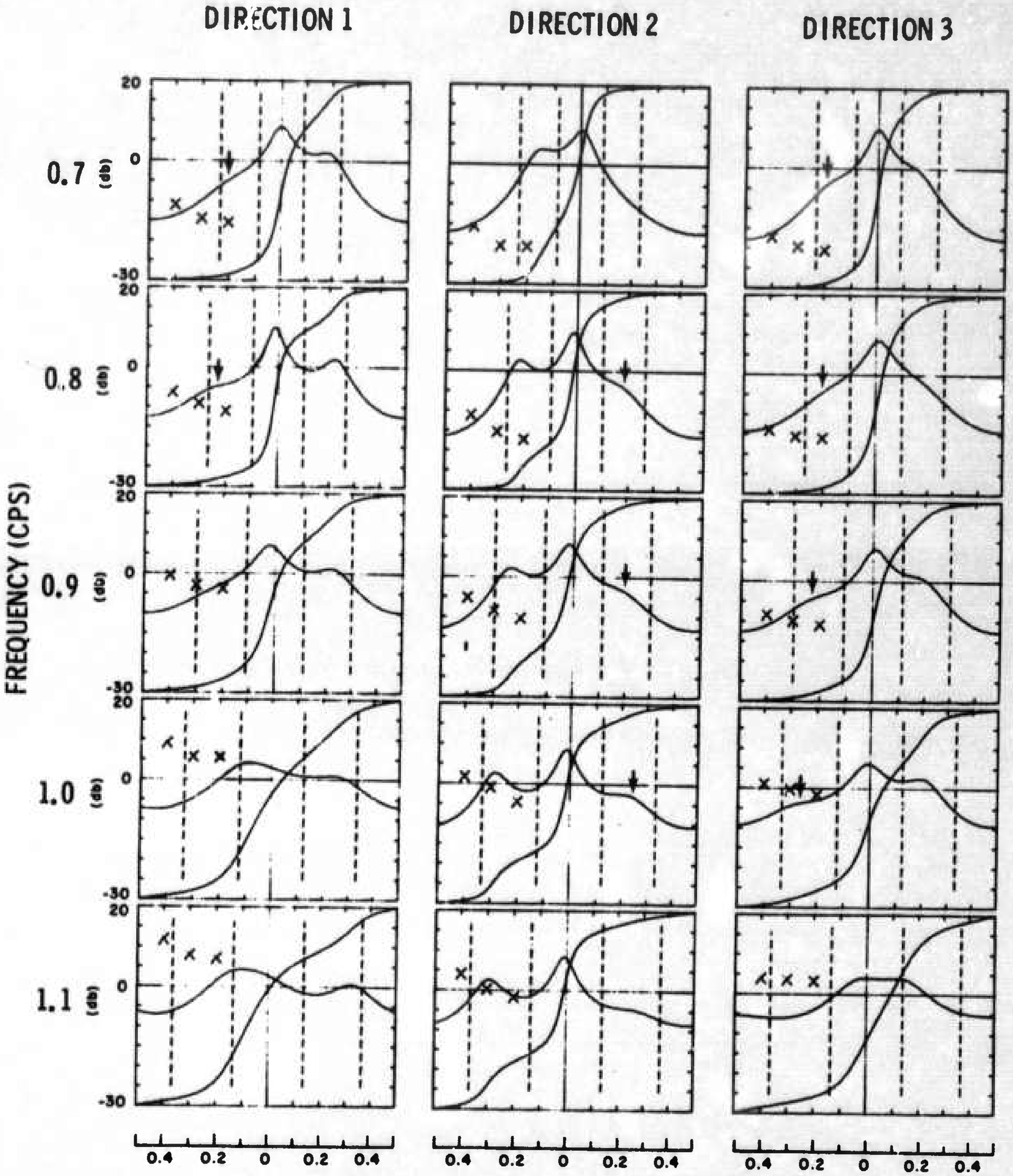


Figure 4. Wavenumber and Integrated Spectra from WMO Noise Sample 3



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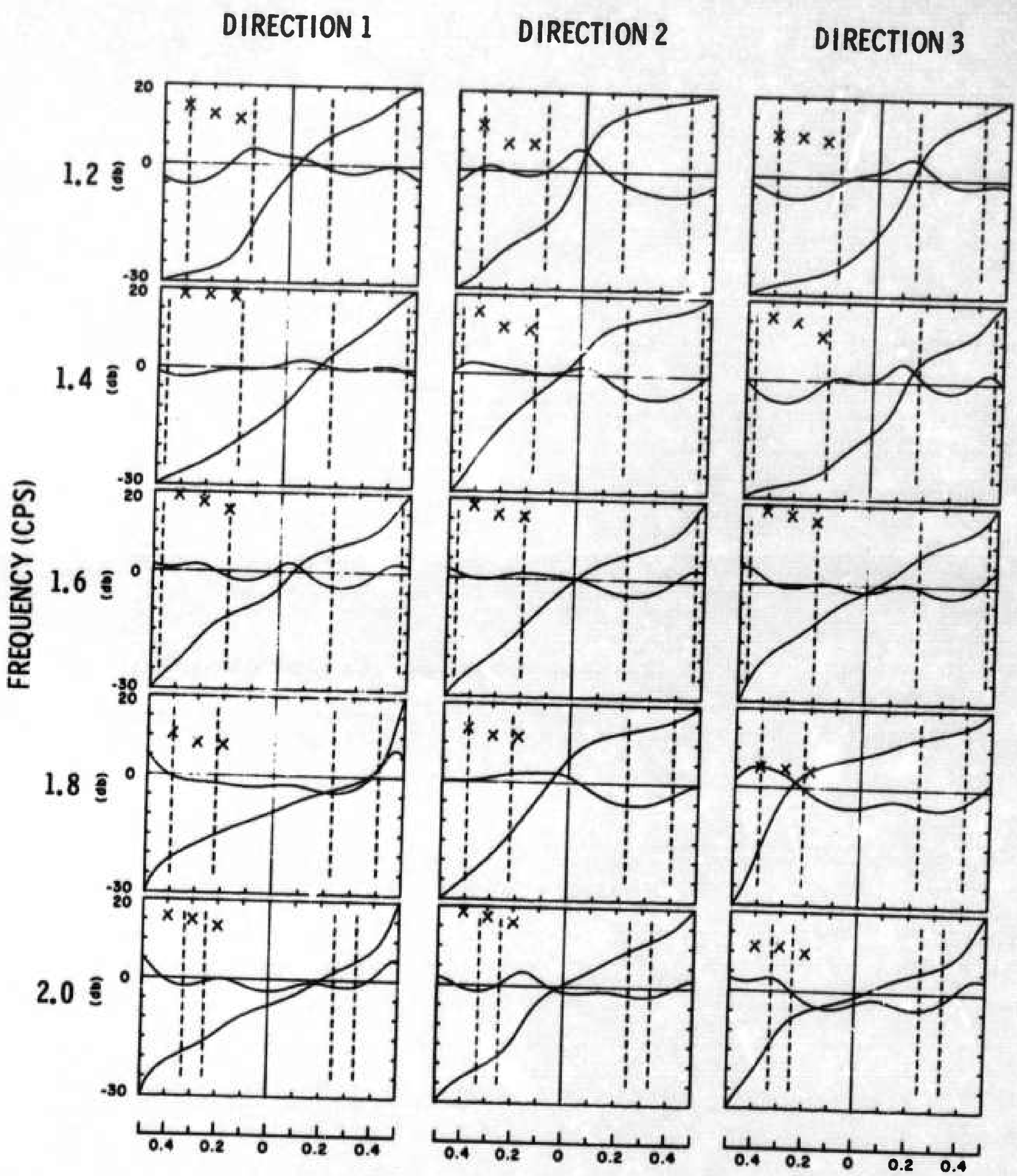

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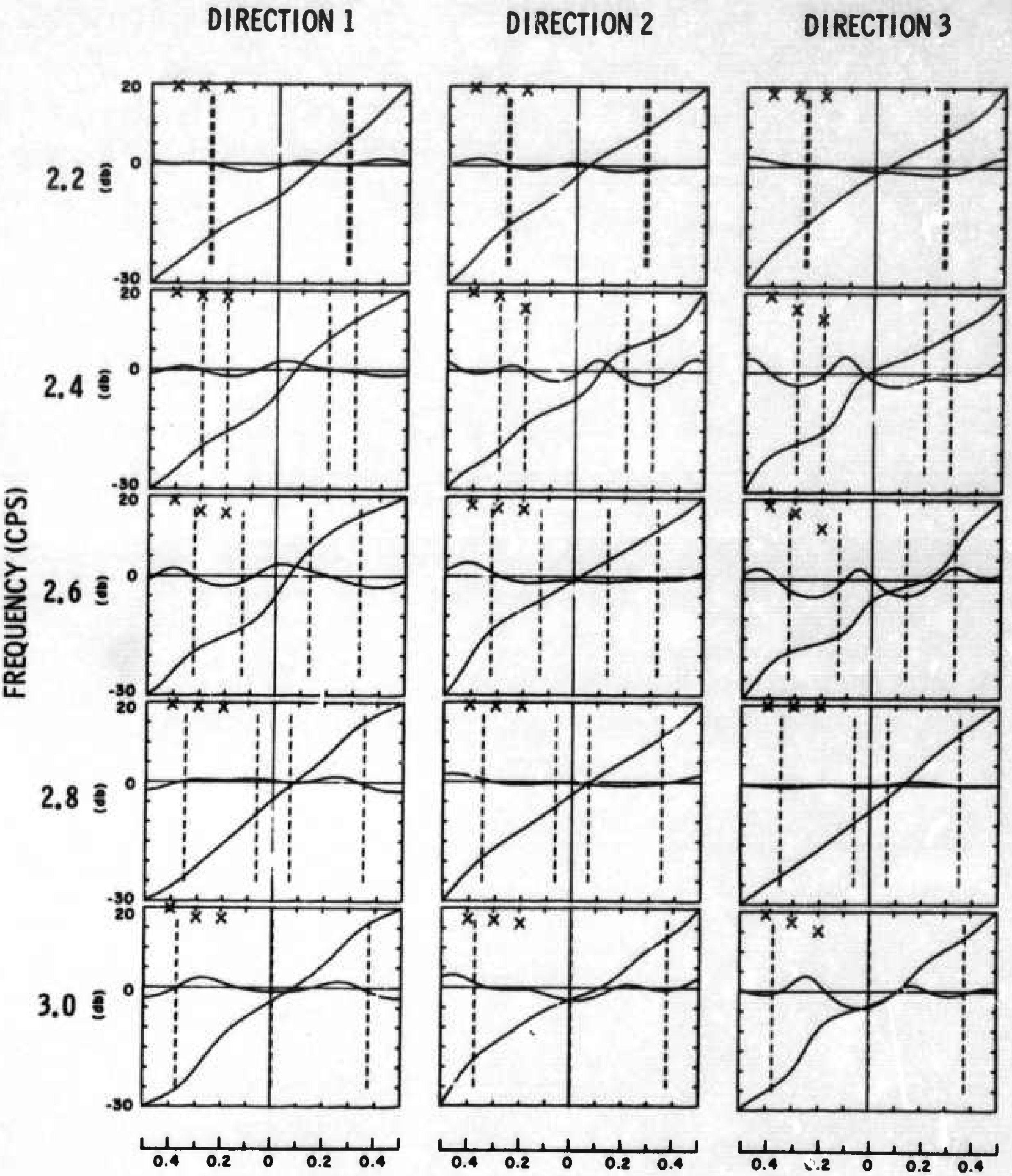


Figure 4. (Contd)

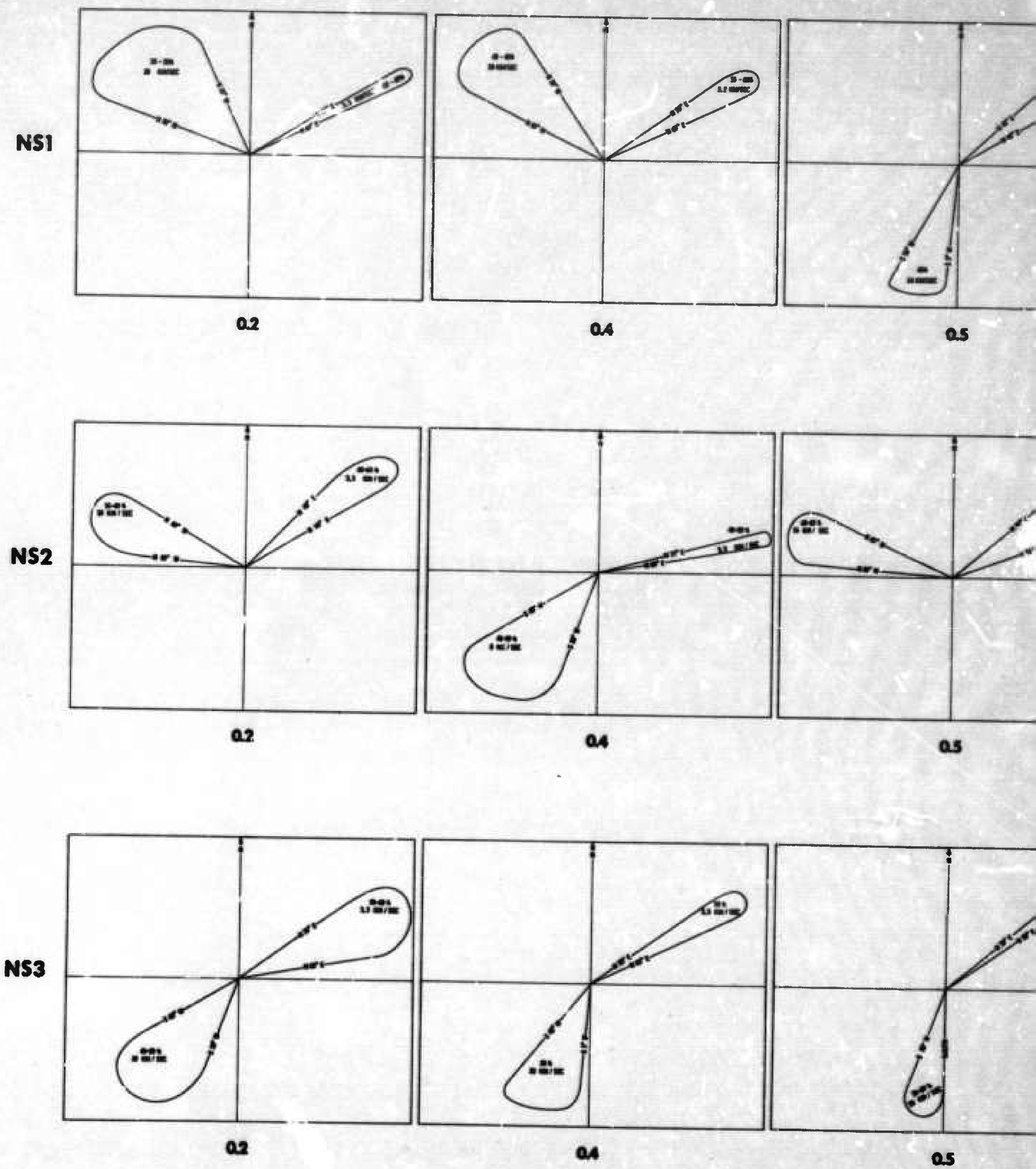
SECTION III

INTERPRETATION OF K-LINE SPECTRA

The spectra presented so far are apparent in the sense that they represent the way each line perceives the noise. To get a true estimate of the spectra, the information for each direction is synthesized for the three noise samples and is presented in Figure 5. This synthesis is possible up to 1.0 cps; above that, the peaks cannot be recognized (except at 2.0 cps, which will be discussed at the end of this section).

The general pattern of the noise is obvious. A common feature in all samples and at all frequencies from 0.2 to 1.0 cps is the presence of Rayleigh energy coming from the northeast. The direction of arriving waves covers a range indicated in the figure. The variability of the direction is apparent, but we can say with confidence that the incoming waves lie within the range of N40°E to N80°E. Velocities of the arriving waves fall between 3.3 km/sec and 2.8 km/sec. Velocity variations with frequency follow no pattern except in NS1 where the decrease in velocity with increase in frequency tends to follow a dispersion curve. Because such behavior is not noted in the other two noise samples, no estimate of a dispersion curve is made. The consistency of the noise in all of the samples, its broadband nature, and the 40° span of the arriving waves suggest the nearby presence of a permanent noise source extending from N40°E to N80°E. The geography of WMO shows lakes Lawtonka and Elmer Thomas in the northeastern region, 5 to 8 km away from the center of the array (Figure 6). This evidence, although circumstantial, leads one to believe that the Rayleigh wave energy is generated by these lakes.

The other major contribution to the total noise comes from the high-velocity noise. The limited spectral resolution of the array precludes any reliable estimate of an average velocity of this noise and makes it impossible to determine its direction, however, such an attempt indicates that this noise may be stronger from the northeast and southeast. Figure 5 indicates the directions in which this energy appears to be stronger.


NS1
NS2
NS3
0.2
0.4
0.5

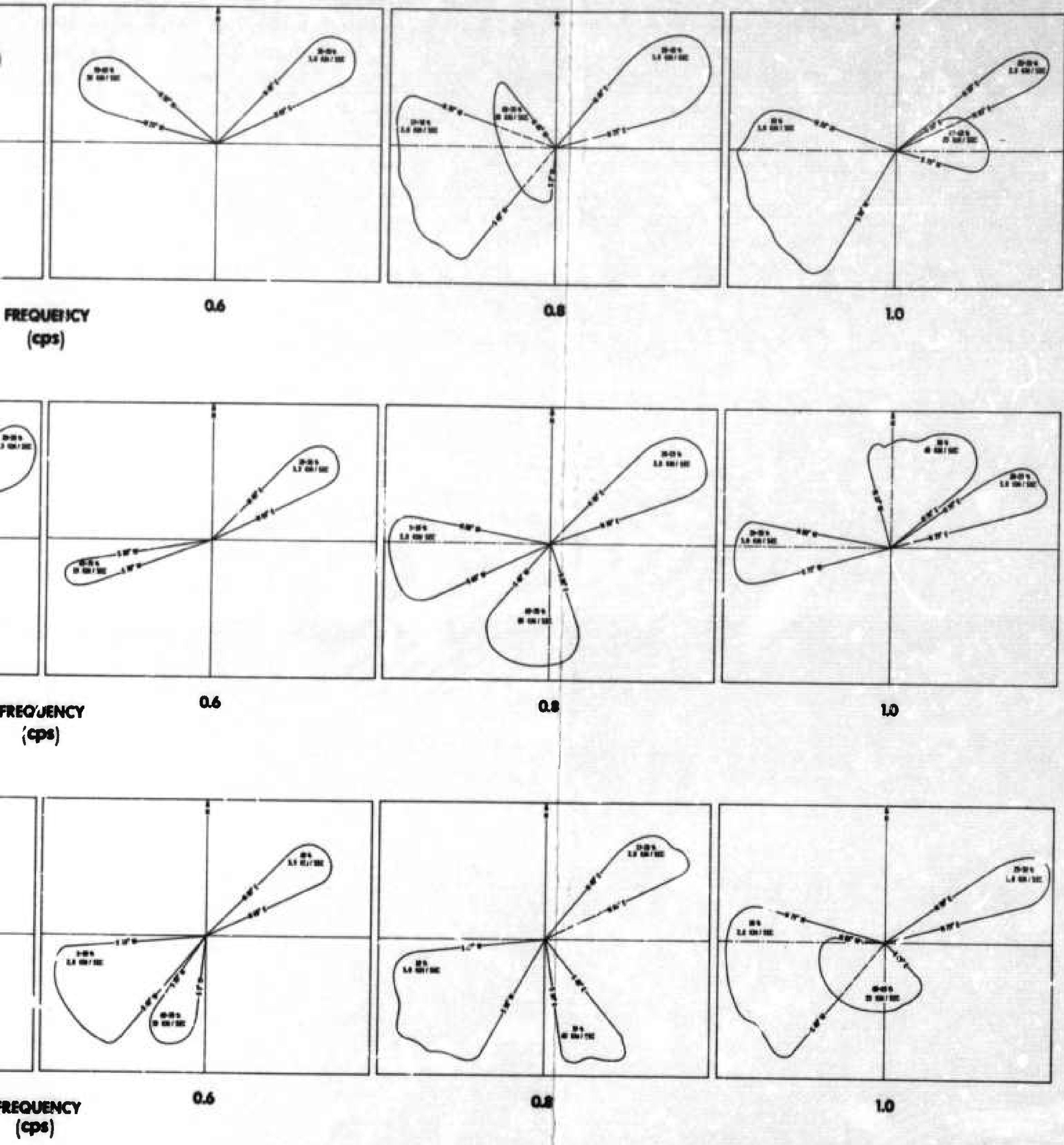


Figure 5. Synthesis of K-Line Spectra

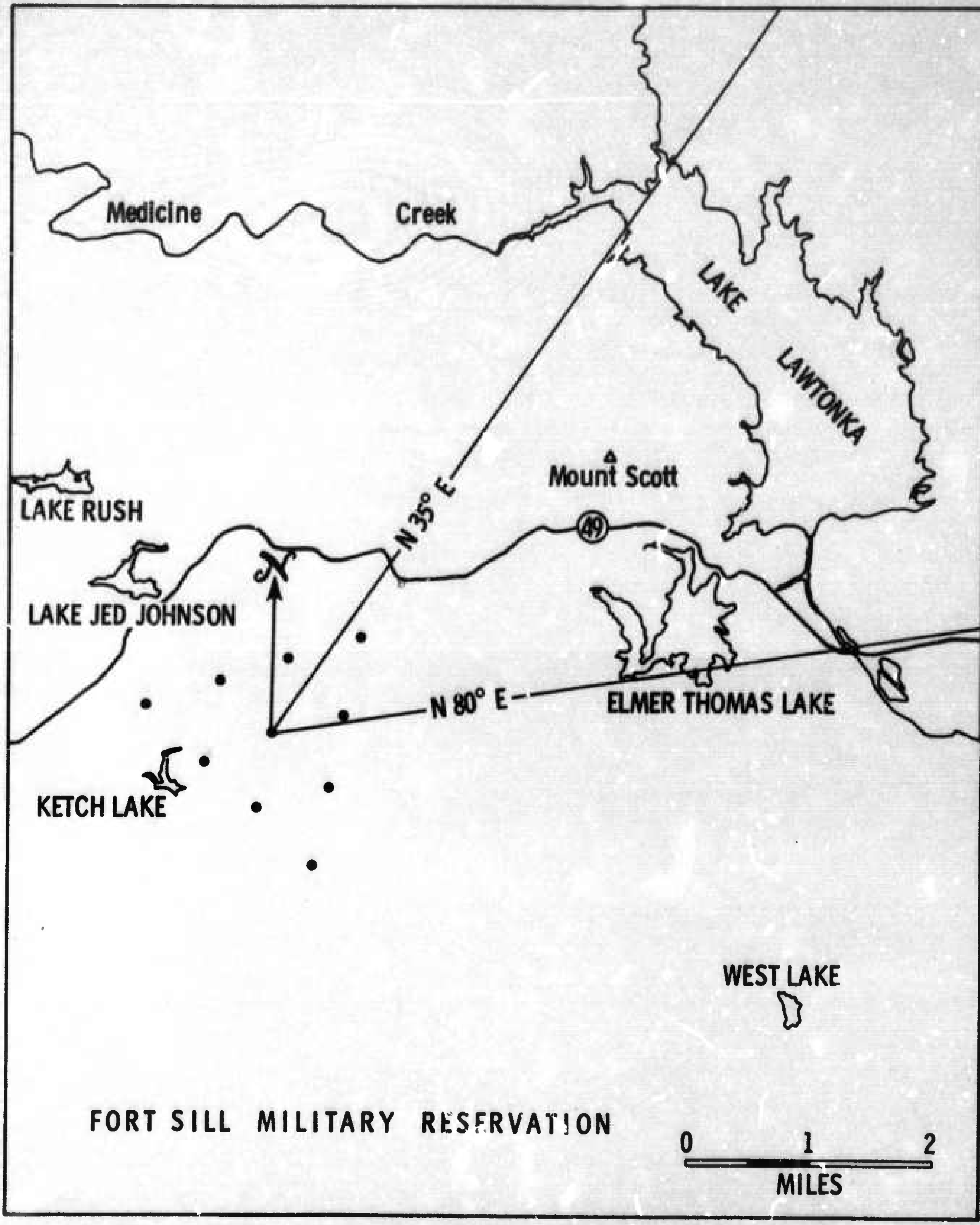


Figure 6. WMO Array and Neighboring Lakes

In addition to the northeastern noise and the high-velocity noise, a new low-velocity contribution to the total noise becomes barely noticeable above 0.6 cps. The approximate positions of the peaks, which are almost concealed by the total noise, are indicated by small arrow marks in Figures 2 through 4. This noise component is probably isotropic (non-directional) Rayleigh-wave energy and seems stronger from the southwest. The directions in which this energy appears to be stronger are shown in Figure 5. Since true estimations of the spectra were only synthesized up to 1.0 cps, behavior above 1.0 cps remains unknown.

The three noise constituents described so far result from the study of K-line spectra covering the frequency range of 0.2 cps to 1.0 cps. Studies above 1.0 cps are difficult because the interference caused by the inhomogeneous geology of the area becomes more pronounced at smaller wavelengths. However, the sharp peak at 2.0 cps, consistent in all of the noise samples, has been studied.

The presence of a 2.0-cps peak at almost all stations in the area has been reported and has aroused considerable interest among many investigators as to the cause of such a peak. So far no convincing explanation has been given, probably because a detailed study of such a peak's nature has yet to be made. The K-line study of this peak at WMO shows great consistency among all the three noise samples (Figures 7 through 9). Due to the aliasing property of the WMO array, three seismically reasonable velocities for the 2.0-cps energy are possible. Thus, a unique direction and velocity has not been assigned to this energy.

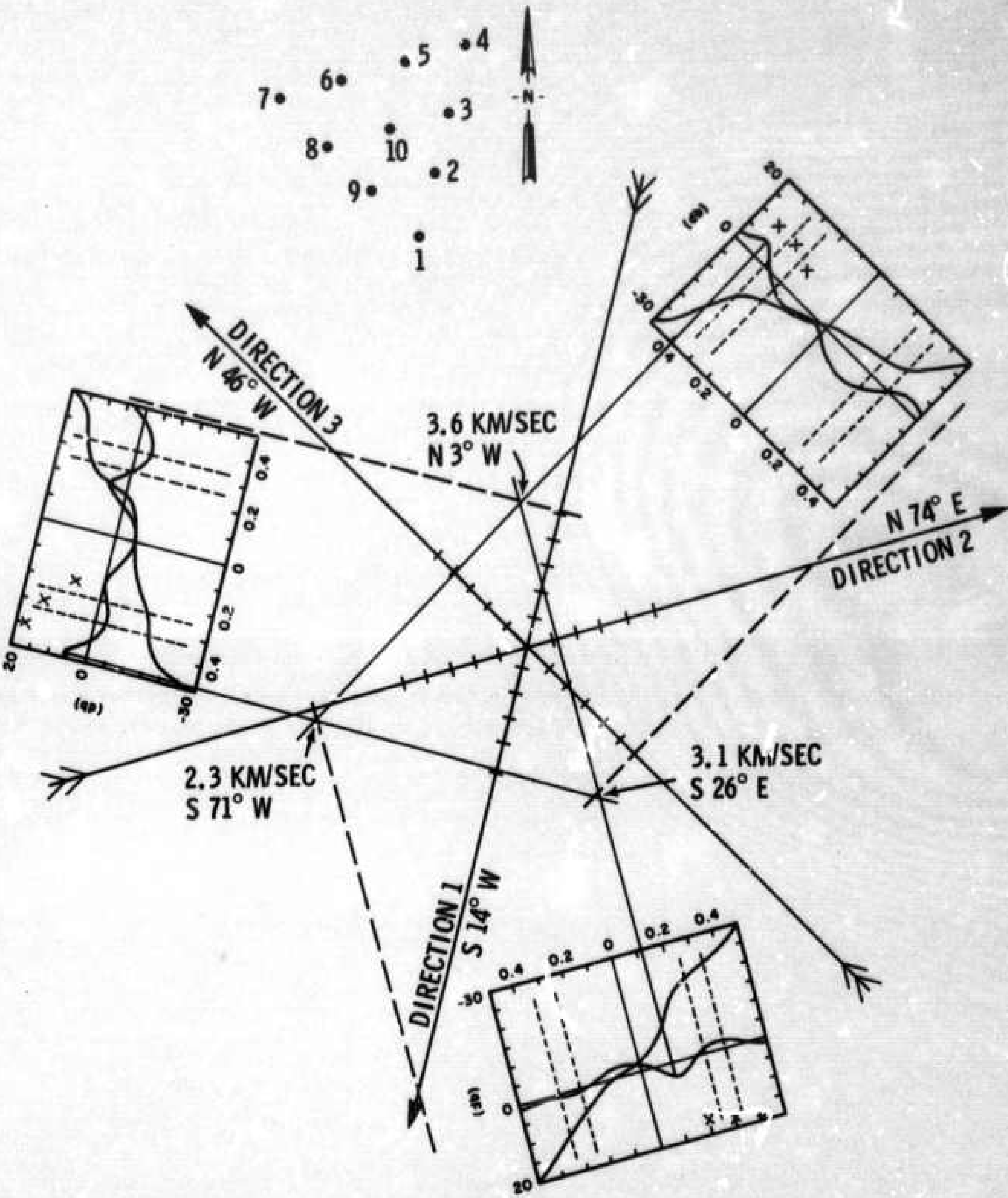


Figure 7. Possible Directions and Velocities of 2.0 cps Peak in Noise Sample 1

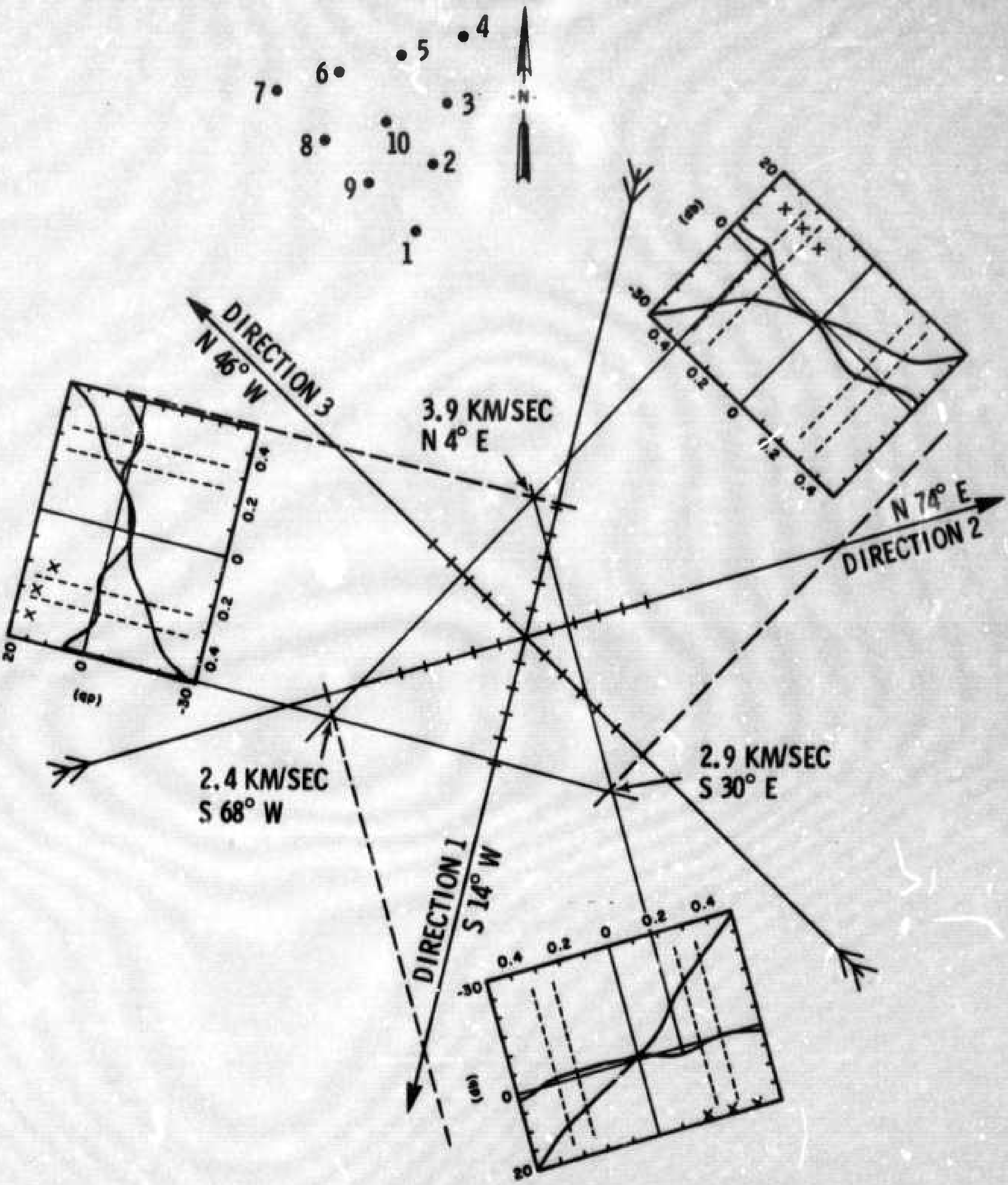


Figure 8. Possible Directions and Velocities of 2.0 cps Peak in Noise Sample 2

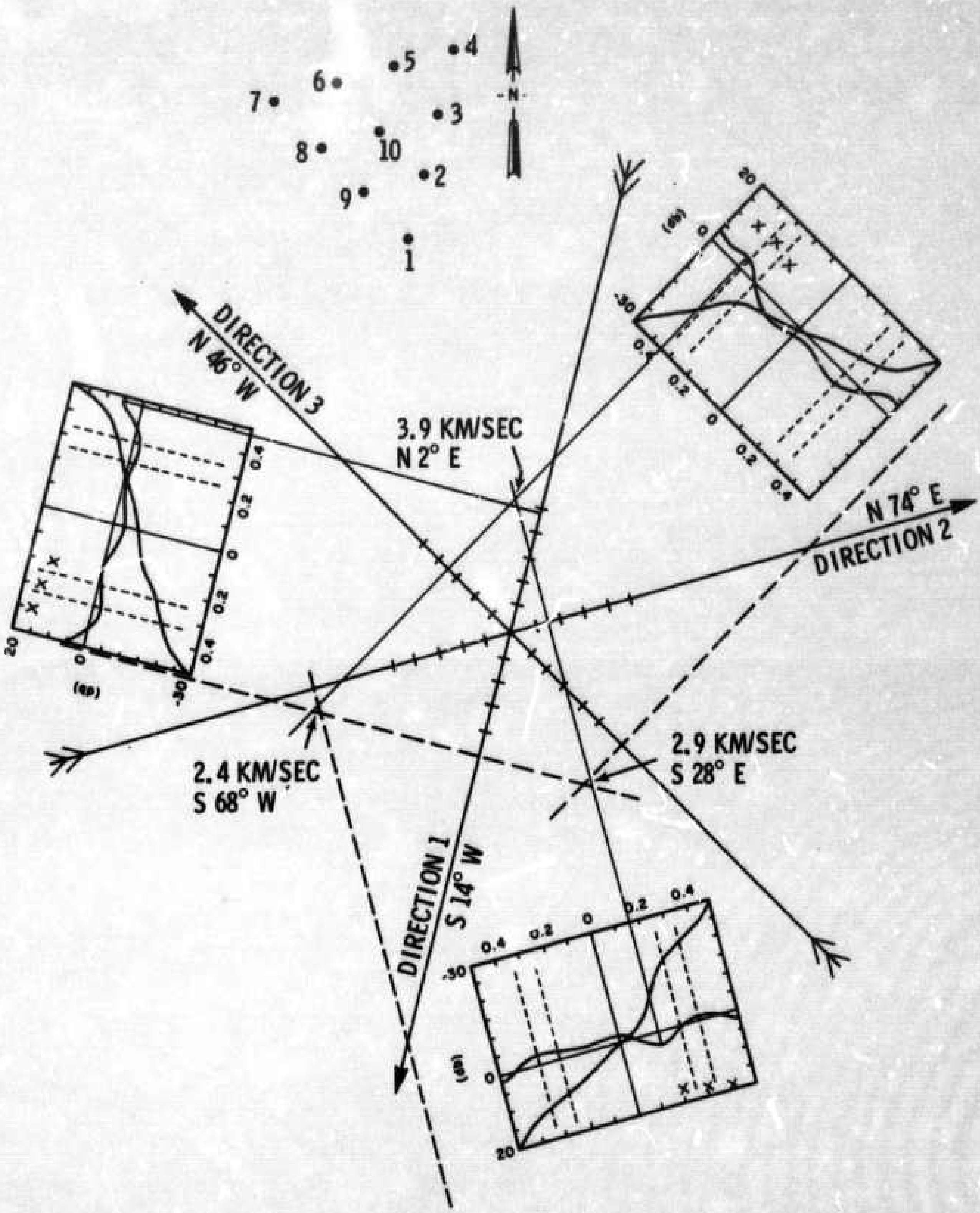


Figure 9. Possible Directions and Velocities of of 2.0 cps Peak in Noise Sample 3

SECTION IV

ABSOLUTE POWER SPECTRA

The noise pattern presented in Figure 5 gives the percentage of each noise constituent's power with respect to the total noise power. To compute the absolute power spectrum of each constituent of the total noise, the absolute power spectrum of the total noise must be computed. Unfortunately, the reliability of the calibration data needed for such a computation has been in question. However, in order to give some idea of the absolute spectrum, the best available estimate of the absolute power spectrum of NS3 is presented in Figure 10, once in terms of ground motion and once as modified by the JM seismometer system. This absolute spectrum indicates that at 1.0 cps the power-density spectrum for this noise sample is about 14.0 db down relative to 1 $(m\mu)^2$/cps. Figure 11 indicates seismometer response. Absolute power spectra for the three constituents of the total noise NS3 are given in Figure 12. The 2.0 cps peak was also evaluated and was found to be 18.3 db down relative to 1 $(m\mu)^2$/cps.

Reliability of the calibration data becomes more questionable when this work is compared with similar work done on TFO (Figure 13). Since WMO is less quiet than TFO, the spectrum at WMO should be higher than the spectrum of TFO; this is not the case when the spectra of these two observatories are compared. Moreover, no explanation is given for the presence of the prominent hump at 0.4 cps in WMO NS3. Both of these happenings are indicative of some sort of low-cut filtering effect applied to the spectrum. Information about these noise recordings is too incomplete to pursue the matter further. New data to be recorded shortly will provide accurate absolute spectral estimates of the seismic noise at WMO.

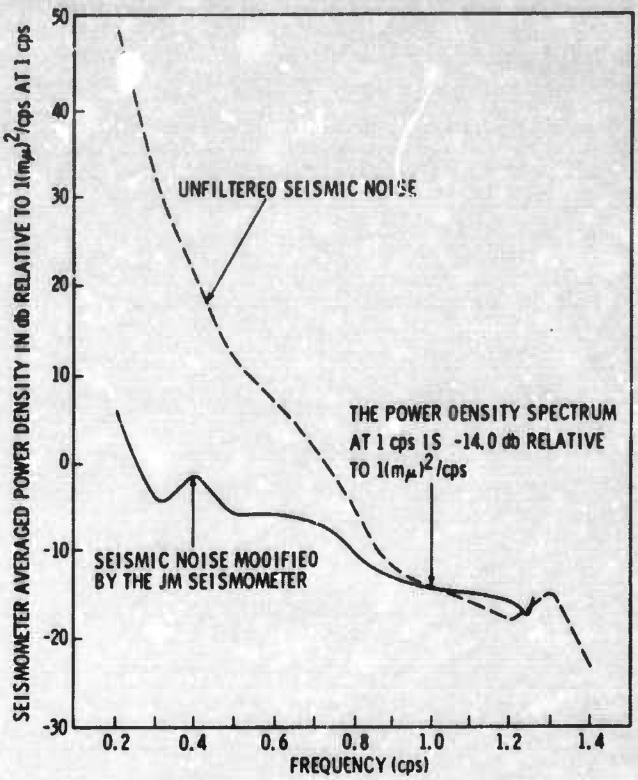


Figure 10. Seismometer-Averaged Absolute Power Density Spectra

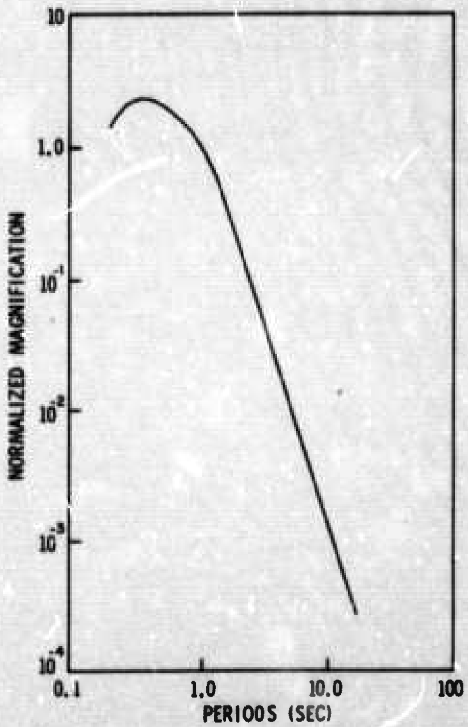


Figure 11. Response of Short-Period JM Seismometer

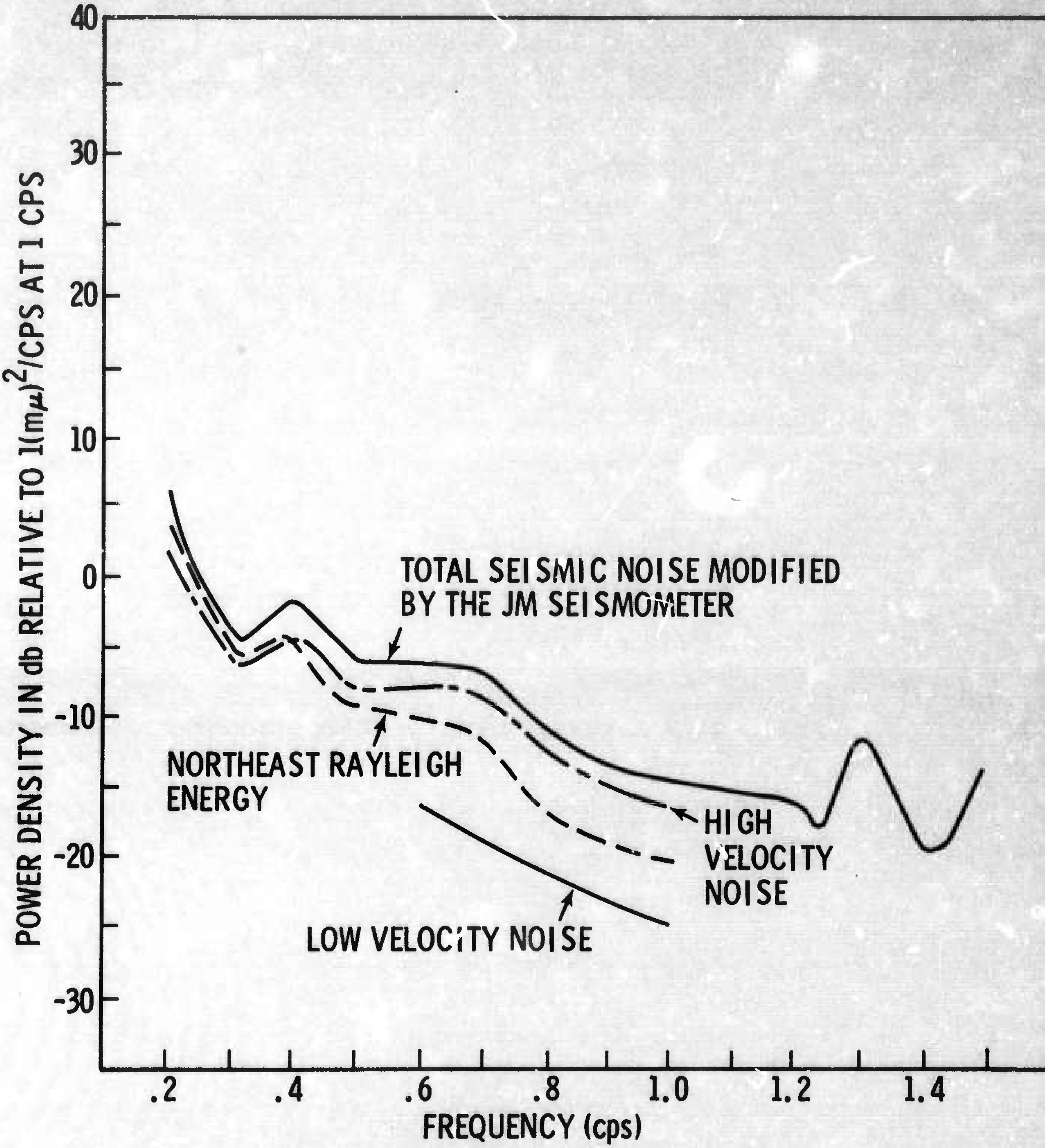


Figure 12. Absolute Frequency Power Density Spectra for Three Noise Components in WMO Noise Sample 3

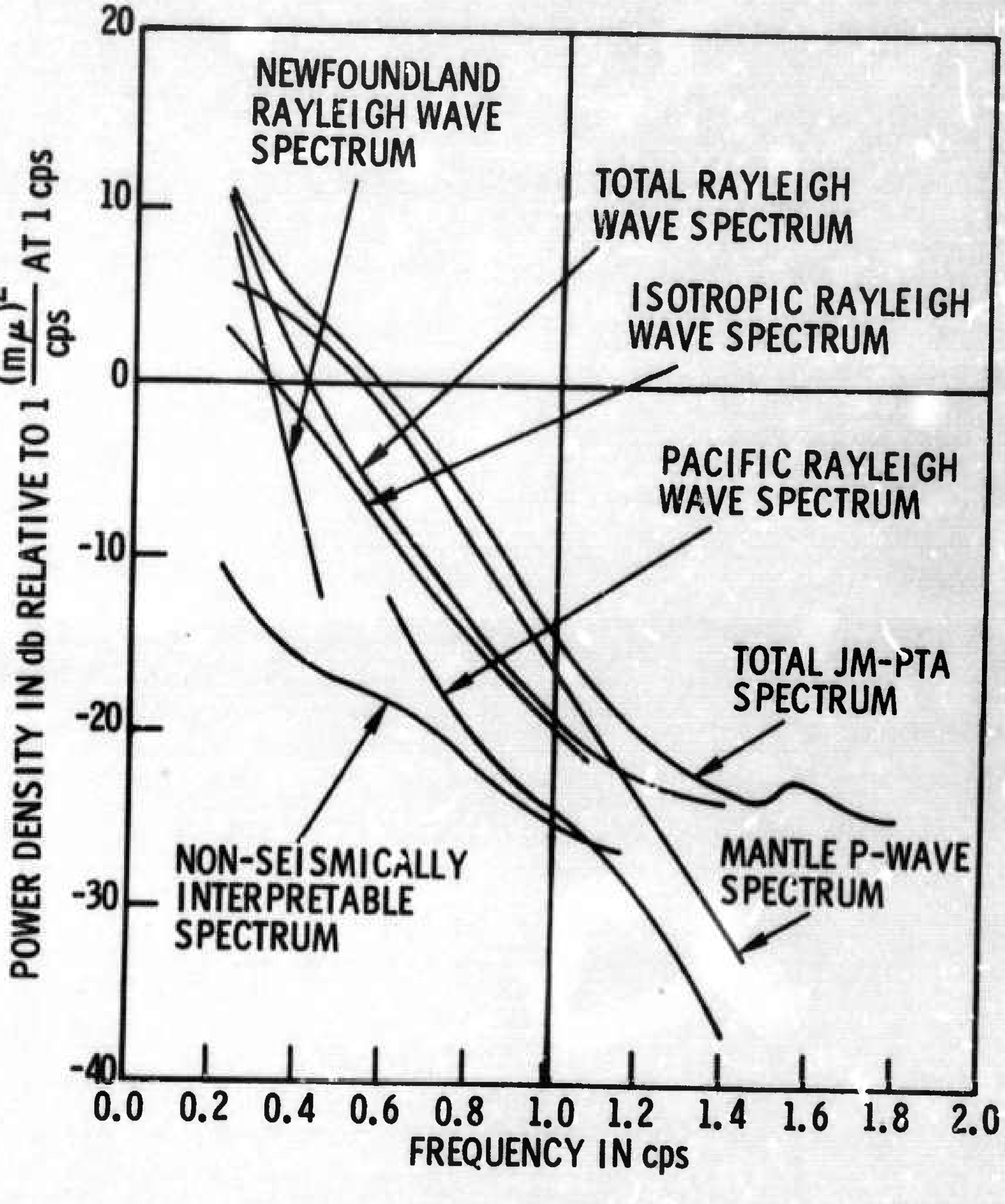


Figure 13. Absolute Frequency Power Spectra in db vs cps for Various Noise Components in the TFO Long Noise Sample

SECTION V

CONCLUSIONS

The present study of WMO noise samples using K-line spectra furnishes information unavailable from previous analyses of the f-k spectra[1,2,3].

The newly discovered northeastern noise is completely extracted from the remainder of the noise; arrival directions, velocity, and power spectra are successfully estimated and related to the noise coming from lakes Lawtonka and Elmer Thomas in the northeast. High-velocity, mantle P-wave noise, which was seen in the TFO noise analysis, is also uncovered. However, an accurate estimation of this noise is not possible due to low spectral resolution. Study of a low-velocity noise appearing at higher frequencies cannot be pursued beyond 1.0 cps because of the disorganized spectra at higher frequencies. Such disorganized spectra is apparently due to the interference of the waves with the inhomogeneous geology of the WMO site which becomes pronounced at smaller wavelengths. In spite of these difficulties at higher frequencies, the 2.0 cps peak is easily recognized and found consistent in all three noise samples. The aliasing properties of the WMO, however, prevent picking a unique direction and velocity for this energy.

Low spectral resolution is due to the small number of seismometers in a line. A similar study of the Tonto Forest Observatory (TFO) long-noise sample,[4] with 11 seismometers in a line, gave a higher spectral resolution than the present study, which uses a maximum of four seismometers in a line. For a detailed study of the high-velocity noise, more seismometers in a line are recommended. While the layout at WMO does not have as many seismometers in a line as at TFO, because wavenumber spectra are available in three directions, high confidence can be placed in its analysis. Syntheses of three spectra in three different directions eliminated many deceptive inferences which would have led to erroneous results, had there been two arms only.

SECTION VI

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2. Texas Instruments Incorporated, 1966: Array Research Semiannual Tech. Rpt. No. 5, Contract AF 33(657)-12747, Jul. 1.

3. Texas Instruments Incorporated, 1967: Array Research Final Rpt., Contract AF 33(657)-12747, Jan. 20.

4. Texas Instruments Incorporated, 1967: Analysis of K-Line Wavenumber Spectra from TFO Long-Noise Sample, Array Research Spec. Rpt. No. 23, Contract AF 33(657)-12747, Feb. 28.

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13. ABSTRACT

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